Journal of
Mechanical
Science and
Technology

Journal of Mechanical Science and Technology 21 (2007) 1752~1755

Optical characteristics of silver film on the moth-eye structure

C. J. Ting[1,2,*], H. Y. Tsai[3], C. P. Chou[1], H. Y. Lin[2] and T. C. Wu[2]

[1]*Mechanical Engineering Department, National Chiao Tung University, Taiwan 300, R.O.C*
[2]*Mechanical and Systems Research Laboratories, Industrial Technology Research Institute, Taiwan 310, R.O.C*
[3]*Department of Mechanical and Mechatronic Engineering, National Taiwan Ocean University, Taiwan 202, ROC*

(Manuscript Received May 31, 2007; Revised August 30, 2007; Accepted September 30, 2007)

Abstract

The development of coating optics to lower the reflected light and thereby to increase the optical efficiency of an optical system has been a very important issue for many years. Conventional solutions to this, such as multilayered alternation of high and low refractive index layers, often lead to an expensive coating process. Recently, the use of anti-reflection structured (ARS) surface, which is called "moth-eye structure", has been proposed as an applicable option based on both the theoretical and experimental studies. In the current study, the experimental results of the reflectance and transmittance of two different thicknesses of silver films deposited on the moth-eye structure were carried out. The moth-eye structure arrays were fabricated by holographic exposure and photolithographic processes on the polymer film. The structure arrays were consisted of periodic length of about 300 nm, with the diameter of about 250 nm and the height of 150 nm. Compared with the silver coating film on the flat PET substrate, the optical property of the silver coating film on the moth-eye structure showed a better result for the anti-reflection application. The 25 nm-thick silver film on the moth-eye structure is suggested to be applied for the car window glass of antireflective films to obtain the high performance of heat insulation with acceptable transparency in the visible range.

Keywords: Anti-reflection; Moth-eye structure; Silver film

1. Introduction

The technical development of optical coating to lower the reflected light and thereby to increase the optical efficiency of an optical system has been a very important issue for hundreds of years. The nano-structure technology not only has been applied to lower the reflected light besides processes of the conventional evaporation, sputtering, or coating, but also has further well-known potential possibilities like sub-wavelength structures, a nano-porous film and a nano-corrugation surface. Recently, the use of anti-reflection structured (ARS) surface has been proposed as an applicable alternative based on both the theoretical and the experimental study [1-4]. In general, methods of lowering the reflection can be divided into two solutions: one is a multilayered alternation of high and low refractive index layers; the other is an inhomogeneous film with a gradual change of index.

The characteristic of the multilayered alteration of high and low refractive index layers is to split an incident beam into a reflected beam and a transmitted beam while optical rays propagate through a surface of a film. If the optical film thickness, the product of the refractive index and the film thickness, is odd times of a one-fourth wavelength of the incident light, the reflective wave destructively interferes with the incident wave and therefore the synthesized wave disappears. Finally, the reflection approximates to zero at a certain expected position. In order to approach extremely low reflection at a wide waveband,

*Corresponding author. Tel.: +886 3 591 6477, Fax.: +886 3 582 0043
E-mail address: jerryting@itri.org.tw

a multilayered structured film is a superior solution to antireflection in a specific waveband.

The idea of the inhomogeneous film with a gradual change of index is to realize the refractive indices of specially designed structures that gradually varied from the index of the air medium to that of the substrate. Reducing the scattering and lowering the reflectance is the most important issue in consideration of the sizes of these structures whilst the optical rays penetrate these structures. Similar structures are the sub-wavelength structure, the nano-porous film and the nano-corrugation surface [5, 6].

Since these antireflection structures were first discovered by Bernhard on the cornea of night-flying moths in 1967 [7], they were called "moth eye" structures. Prominences on the moth eye are the antireflective structures in nature. For the further application based on the antireflection of the moth-eye structure, to obtain a glass or a film of high reflectance in the infrared spectral region and high transmittance in the visible waveband is an important target in consideration of both safety and heat insulation.

In the current study, the experimental results of the reflectance and the transmittance of two different thicknesses of silver deposited films on the moth-eye structures were first carried out. The moth-eye structure arrays were fabricated by holographic exposure and photolithographic processes on the polymer film. This structure arrays were consisted of the periodic length of about 300 nm, with its diameter of about 250 nm and its height of 150 nm. Compared with the silver coating film on the flat PET substrate, the optical property of the silver coating film on the moth-eye structure showed a better result for the anti-reflection application.

2. Experiments

In order to obtain the moth-eye structures, the structure arrays were fabricated by holographic lithography and photolithographic process on a PET substrate. This structure arrays were consisted of the periodic length of about 300 nm, with the diameter of about 250 nm and the height of 150 nm. A silver film was deposited on the obtained moth-eye structure arrays by a conventional plasma enhanced sputtering system. Since a metal film reflects light easily, the metal film can not be too thick—generally less than 50 nm. The thicknesses of 25 nm and 50 nm were fabricated on the moth-eye structure arrays in the current study. In order to compare the optical characteristics of the silver film on the moth-eye structure, a silver film was also deposited on the PET substrate without moth-eye structures for the thicknesses of 25 nm and 50 nm.

Atomic force microscope (AFM) images were taken by Digital Instrument D3000 as shown in Fig. 1. Since the transmittance and reflectance were required to recognize the optical characteristics of the moth-eye structure arrays with silver film, a spectrophotometer of model Jasco v-570 was used.

3. Results and discussion

Fig. 2 shows the comparison of the transmittance and the reflectance of light propagating through the 25 nm-thick silver film on the moth-eye structure and the bare moth-eye structure in the spectrum range of 250 nm to 2500 nm. From the experimental results, the transmittance is largely decreased after silver film is deposited, though it is kept at certain large value, above 30 %, in the range of visible waveband. The reflectance of the silver film on the moth-eye structure is largely increased, especially in the infrared

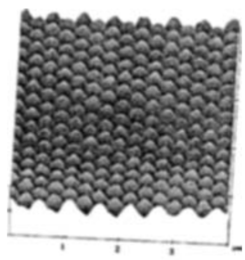

Fig. 1. AFM image of moth-eye structure arrays. Periodic length and diameter are about 300 nm.

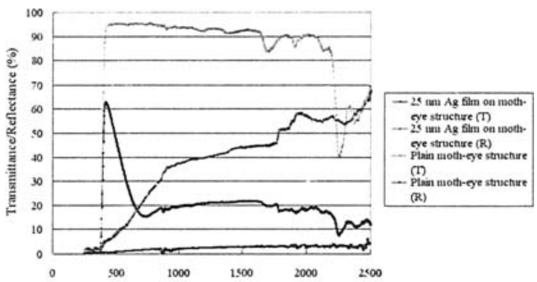

Fig. 2. The comparison of the transmittance and the reflectance of light propagating through the 25 nm-thick silver film on the moth-eye structure and the bare moth-eye structure in the spectrum range from 250 nm to 2500 nm.

range. From both results above, it can be easily understood that the metal film lowers the transmittance and the metal reflects a large amount of light easily. For the application of the car window glass with high transmittance in the visible waveband and high reflectance in the infrared range, a 25 nm-thick silver film on the moth-eye structure can avoid much light of large wavelength transmitting through the film and therefore heat insulation.

Fig. 3 shows the comparison of the transmittance and the reflectance of light propagating through the silver film of 50 nm on the moth-eye structure and the bare moth-eye structure in the spectrum range from 250 nm to 2500 nm. From the experimental results, the transmittance largely decreases to less than half of the magnitude after a silver film is deposited, though it is kept above 20 % in the range of a visible waveband. The reflectance of the silver film on the moth-eye structure largely increases, especially in the infrared range. From Fig. 2 and Fig. 3, it can be understood that the thicker the metal film is, the lower is the transmittance and the larger is the reflectance. For the target application of the car window glass in the current study, though a silver film of 50 nm on the moth-eye structure can avoid much infrared light transmitting through the film and therefore heat insulation, the transmittance in the visible waveband is too low to see clearly through the film/structure.

Fig. 4 shows the comparison of the transmittance and the reflectance of light propagating through the silver film of 25 nm both on the flat PET substrate and on the moth-eye structure in the spectrum range of 250 nm to 2500 nm. Fig. 5 shows the comparison of the transmittance and the reflectance of light propagating through the silver film of 50 nm both on the flat PET substrate and on the moth-eye structure in the same spectrum range. The reflectance and the transmittance profile versus the wavelength of silver coating film on moth-eye structure are shifted to a large wavelength domain than those of silver film on the PET substrate for about 250 nm to 330 nm and 70 nm, respectively. As for the transmittance, it has broader band for the case of the 50 nm-thick silver film on the moth-eye structure than that for the case of the 50 nm-thick silver film on the PET substrate in the visible range. However, the reflectance of the 50 nm-thick silver film on the moth-eye structure is larger than that of the 50 nm-thick flat PET substrate in the range of the wavelengths larger than 900 nm, which differs from the case of 25 nm. If the heat insulation or the avoidance of the infrared incidence is the main issue for a certain application, the 50 nm-thick silver film deposited on the moth-eye structure can be taken into consideration.

To sum up these experimental results, Table 1 shows the transmittance and the reflectance of different cases discussed in the current study for some specific visible wavelengths. The 25 nm-thick silver film on the moth-eye structure is considered for the

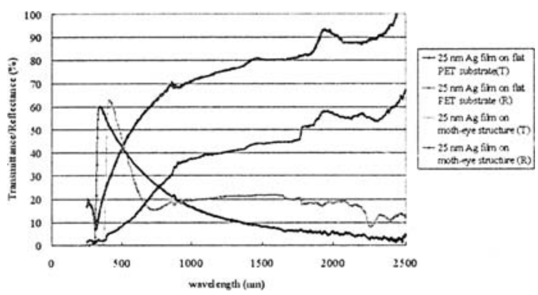

Fig. 4. The comparison of the transmittance and the reflectance of light propagating through the silver film of 25 nm both on the flat PET substrate and on the moth-eye structure in the spectrum range from 250 nm to 2500 nm.

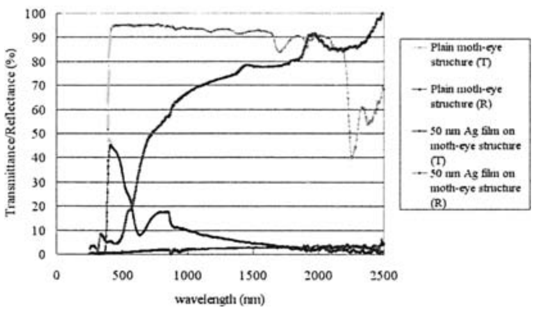

Fig. 3. The comparison of the transmittance and the reflectance of light propagating through the silver film of 50 nm on the moth-eye structure and the bare moth-eye structure in the spectrum range from 250 nm to 2500 nm.

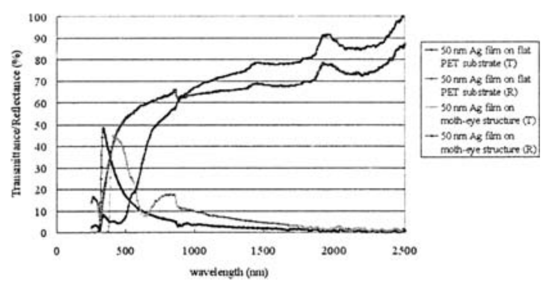

Fig. 5. The comparison of the transmittance and the reflectance of light propagating through the silver film of 50 nm both on the flat PET substrate and on the moth-eye structure in the spectrum range from 250 nm to 2500 nm.

Table 1. The transmission and reflectance of different film conditions are summarized in some specific visible wavelength.

Film \ Wavelength(nm)		Transmittance (%) 400	550	700	Reflectance (%) 400	550	700
Moth-eye structure		82.2	95.1	95.2	0.58	0.68	1.40
Silver film on moth-eye structure	25	57.1	35.9	15.9	4.52	10.6	20.6
	50	41.0	23.9	12.5	5.21	18.1	48.2
Silver film on PET substrate	25	53.2	38.3	28.6	26.8	47.6	59.9
	50	31.8	13.2	7.7	39.1	55.3	61.1

application of the car window glass or antireflective films to obtain the high performance of heat insulation with acceptable transparency in the visible range.

4. Conclusions

The moth-eye structure arrays of the periodic length of about 300 nm, with the diameter of about 250 nm and the height of 150 nm were fabricated by holographic exposure and photolithographic processes on the polymer film in the current study. Compared with the silver coating film on the flat PET substrate, the optical property of the silver coating film on the moth-eye structure shows a better result for the anti-reflection application. The reflectance of the 25 nm-thick silver film on the moth-eye structure is 10.6 on the wavelength of 550 nm, and that of the 25 nm-thick silver film on the PET substrate is 47.6. The reflectance of the 50 nm-thick silver film on the moth-eye structure is 18.1 on the wavelength of 550 nm, and that of the 50 nm-thick silver film on the PET substrate is 55.3. As for the transmittance, it has higher value for the case of the 50 nm-thick silver film on the moth-eye structure than that for the case of the 50 nm-thick silver film on the PET substrate in the visible range. However, as for the transmittance for the cases of the 25 nm-thick silver film, it does not show obvious improvement on either the moth-eye structure or the flat PET substrate. Besides, the reflectance and the transmittance profile versus the wavelength of silver coating film on moth-eye structure are shifted to a large wavelength domain than those of silver film on the PET substrate for about 250 nm to 330 nm and 70 nm, respectively. The 25 nm-thick silver film on the moth-eye structure is considered to be applied for the car window glass or antireflective films to obtain the high performance of heat insulation with acceptable transparency in the visible range.

Acknowledgements

The authors would like to thank the financial support of National Science Council, R.O.C., through the project NSC 95-2221-E-019-096.

References

[1] M. Niggemann, B. Blaesi, V. Boerner, A. Gombert, M. Klicker, V. Kuebler, P. Lalanne, and V. Wittwer, Periodic microstructures for large area applications generated by holography, *SPIE.* 4438 (2001) 108-115.

[2] H. Toyota, and A. Mizutani, Design and fabrication of guided-mode resonant grating filter with antireflection structured surface, *SPIE.* 5184 (2003) 89-98.

[3] V. Boerner, S. Abbott, B. Blaesi, A. Gombert, and W. Hoβfeld, Holographic antiglare and antireflection Films for flat panel displays, SID Symp. Dig. Tech. Papers. 34 (2003) 68-71.

[4] Z. Yang, D. Zhu, M. Zhao, and M. Cao, The study of a nano-porous optical film with the finite difference time domain method, *J. Opt. A: Pure Appl. Opt.* 6 (2004) 564-568.

[5] Y. Li, Y. Kanamori, and K. Hane, A new method for fabrication nano-porous aluminum grating array, *Microsyst. Technol.* 10 (2004) 272-274.

[6] U. Schulz, Review of modern techniques to generate antireflective properties on thermoplastic polymers, *Appl. Opt.* 45 (2006) 1608-1618.

[7] C. G. Bernhard, Structural and functional adaptation in a visual system, *Endeavour.* 26 (1967) 79-84.